

DETERMINATION OF THE SSME HIGH PRESSURE OXIDIZER TURBOPUMP BEARING TEMPERATURE*

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ABSTRACT

The SSME high pressure liquid oxygen turbopump (HPOTP) bearings sometimes wear and experience heating and oxidation of the ball and raceway surfaces. So far it has been impossible to measure the temperature of the bearings directly during operation of the turbopumps. However, a method was developed for determining the surface temperature of the bearings from the composition of the oxides using oxidation samples for calibration and Auger Electron Spectroscopy (AES) for chemical analysis.

INTRODUCTION

The high pressure oxygen turbopump bearings of the liquid hydrogen/liquid oxygen Space Shuttle Main Engines (SSME) sometimes experience heating and oxidation of the ball and raceway surfaces. This facilitates wear. For expendable vehicles wear is not a problem. However, for reusable vehicles like the Space Shuttle many missions are required between bearing replacements in order to achieve economical operation.

The high pressure oxygen turbopump bearings are angular contact bearings operating at 30,000 rpm and DN levels of 1.7×10^6 [rpm \times mm] in flowing liquid oxygen for cooling. They are made of AISI 440C stainless steel with a PTFE impregnated glass fiber ball retainer. The lubrication is intended by transfer of PTFE from the retainer to the balls and to the ball/raceway interface. Because of the complexity of the turbopump design and the hostile environment it has not been possible to measure the surface temperature of the bearing components directly.

Because of the surface heating and the environment, the balls and raceways are covered with oxides. The chemical composition of oxides depend very much on the alloy composition and the temperature at which they are formed (Refs. 1-3). Therefore, it should be possible to determine the surface temperature of the bearings from the oxide composition. Since no relevant data on the effect of temperature on the oxide composition of AISI 440C could be found in the published literature, a program was initiated to determine the oxide composition at different temperatures under conditions similar to those existing in the turbopump bearings using Auger electron spectroscopy (AES). The composition of the oxides on the bearing surfaces were then measured using AES, and the temperature of the bearings determined by comparing with the data from the oxidation samples.

*This work was supported by NASA Contract No. NAS8-4000 to Rockwell International, Rocketdyne Division.

EXPERIMENTAL PROCEDURE

The 4 mm wide by 50 mm long oxidation samples were cut from AISI 440C bar stock and ground on SiC paper to 500 m thickness followed by polishing with diamond and 0.05 m Al_2O_3 to a metallographic finish on the side to be studied. The back side was finished on 600 grit SiC paper. A 15 mm long center portion of the sample was thinned to 200 m thickness to provide a gauge section of uniform temperature. Three thermocouples were attached to the back side of the gauge section. The samples were clamped at both ends in a specially designed fixture that allowed resistance heating to the desired temperature which was monitored by the thermocouples.

Since the oxygen pressure in the turbopump bearing is 2 MPa and it was desirable to perform the experiments in the Auger chamber, it was necessary to determine if the 0.1 MPa Auger chamber pressure would yield the same results as the higher pressure. Identical time and temperature experiments were therefore performed in a pressure vessel as well as in the Auger chamber.

The exact length of time at which the bearing surface was at a specific temperature was not known but was estimated to lie between 50 and 500 s. Some experiments were, therefore, performed at the same pressure and temperature for 50 and 500 s to assess the effect of time on the composition of the oxides. A temperature range of 450 to 1065°C was covered by this study.

Every experiment in the Auger chamber involved pumping the chamber down to 1×10^{-9} torr at room temperature and ion sputter cleaning the polished sample surface. AES spectra were recorded to confirm that the sample was clean. Oxygen was then admitted to a pressure of 0.1 MPa and the sample was heated to the desired temperature and time. After cooling to room temperature and evacuating the chamber, the in-depth concentration profile through the oxide was recorded. The pressure vessel experiments at 2 MPa oxygen pressure were conducted on samples that had been ion-sputter cleaned in the Auger chamber before transfer to the vessel. After oxidation the sample was again transferred to the Auger chamber and depth profiled. Care was taken to ensure that the experimental and analytical conditions were the same for all experiments.

The balls from the bearings that were studied had been running in hot-fired turbopumps. They were placed in specially designed holders to ensure consistent conditions, and the concentration depth profiles through the oxides were recorded in the same way as for the oxidation samples.

RESULTS AND DISCUSSION

The AES spectrum of clean AISI 440C is shown in figure 1 and typical spectra from the 545 and 900°C oxidation samples are shown in figures 2 and 3, respectively. Note that at the higher temperature Mn and V are present and the Cr peak is significantly increased relative to the Fe peak. Mn and V were first detected at 640 and 725°C, respectively. That the higher temperature oxides would contain more Cr than the lower temperature oxides was expected (Refs. 1-3). However, a number of oxides can form on stainless steels (Refs. 1-3), and the AES spectrum alone cannot be used to conclusively identify them and their relative proportions. Since the Cr/Fe ratio is sensitive to the temperature of oxidation it was used to quantify the oxide composition.

Figure 4 shows that there is little effect of pressure and time on the oxide composition within our range of interest. Therefore, the experiments were performed in the Auger chamber at 0.1 MPa pressure for 500 s at different temperatures.

The depth concentration profiles for the temperatures studied are plotted as Cr/Fe ratio vs sputter time in figure 5. Taking the Cr/Fe ratio at the level portion near the oxide surface of the curves for the different temperatures in figure 5, a Cr/Fe vs temperature calibration curve was obtained in figure 6.

On the average two worn balls from each of twelve bearings from eight turbopumps were analyzed in at least two representative locations. Typical AES spectra at different sputter times are shown in figure 7. Note that no Mn or V are present. The C is normal organic contamination, and the thin layer of F, Se, K and Ca are transferred ball retainer material. The oxide composition depth profile corresponding to the sample in figure 7, is shown in figure 8. Note how little the Cr/Fe ratio varies with depth. This was typical for all worn bearings. It was this through-the-oxide uniform composition feature that justified using the plateau values of the composition depth profiles of the oxidation samples (fig. 5) to construct the Cr/Fe vs temperature calibration curve (fig. 6). Taking the maximum Cr/Fe ratio from the depth profiles for each bearing analysis, it was found to vary between 0.32 and 0.62 for all the bearings analyzed. Using the calibration curve in figure 7 and the Cr/Fe ratio of the bearings, the bearing surface temperature was determined to lie between 500 and 600°C as shown in figure 9. That no Mn was detected in the oxide on the bearings is another indication that the bearings did not reach 640°C temperature.

CONCLUSIONS

It has been shown that it is possible to determine the surface temperature of bearings operating in a liquid oxygen environment from the composition of the oxides. However, the method requires that oxide composition vs temperature calibration data for the particular alloy of interest is available for conditions similar to those existing in the bearings. Using this approach it was possible to show that for the SSME HPOTP bearings studied the maximum temperature was 600°C.

REFERENCES

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2. P. Kofstad, High-Temperature Oxidation of Metals, John Wiley & Sons, 1966.
3. K. Hauffe, Oxidation of Metals, Plenum Press, 1965.

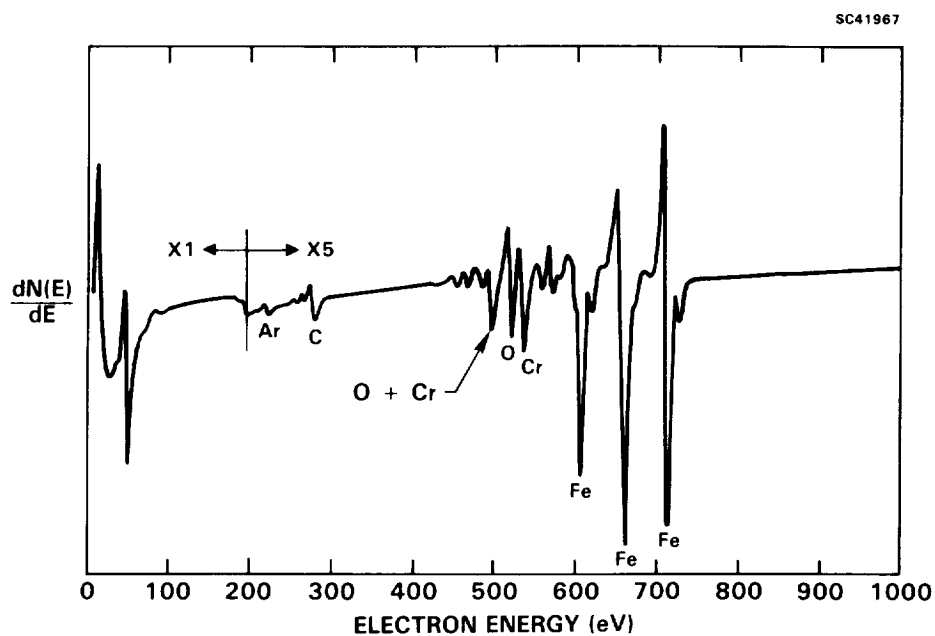


Figure 1 Typical AES spectrum of Ar ion-sputtered AISI 440C before oxidation.

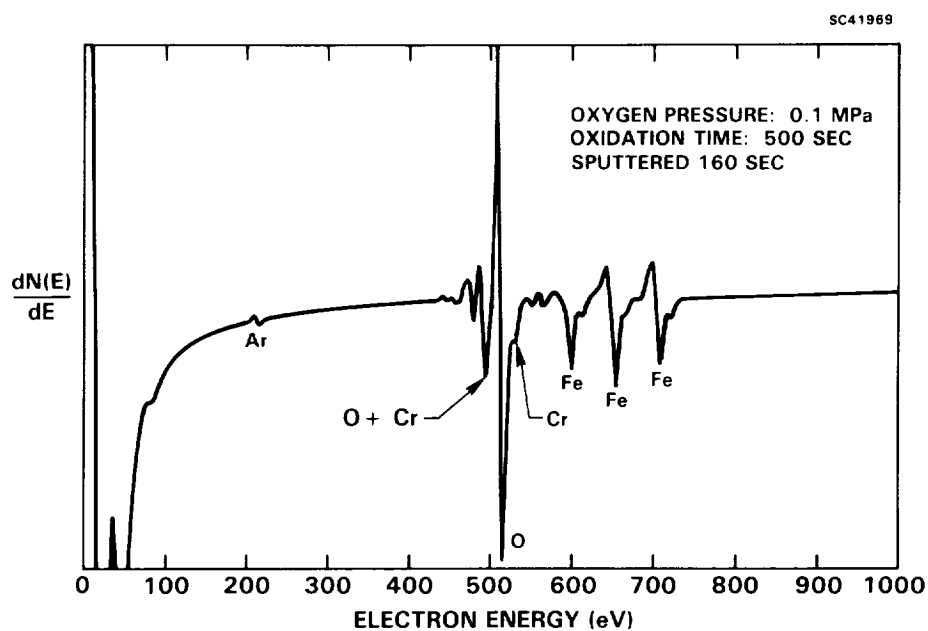


Figure 2 AES spectrum of AIS 440C after oxidation at 545°C for 500 s in 0.1 MPa oxygen.

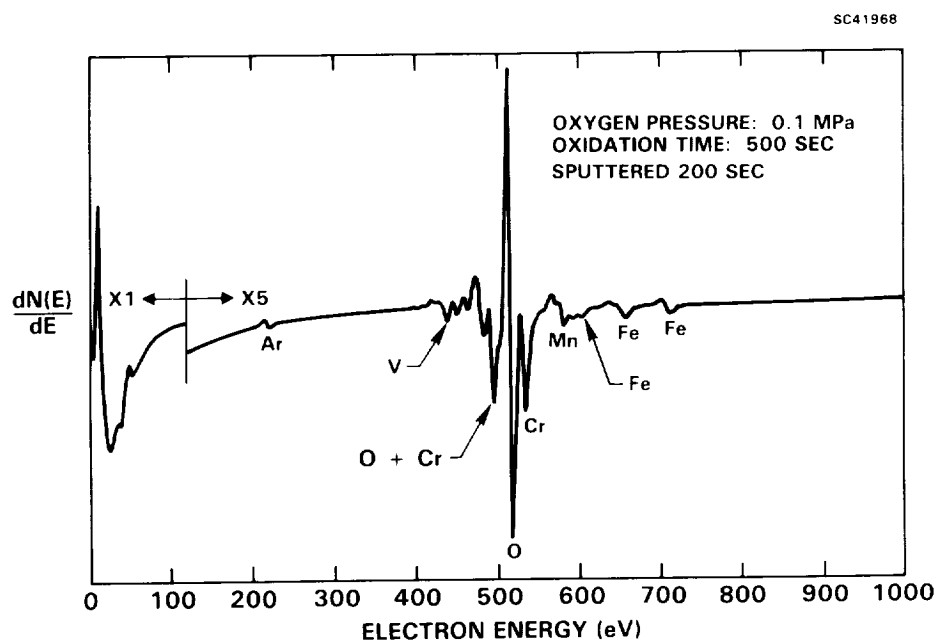


Figure 3 AES spectrum of AISI 440C after oxidation at 900°C for 500 s in 0.1 MPa oxygen.

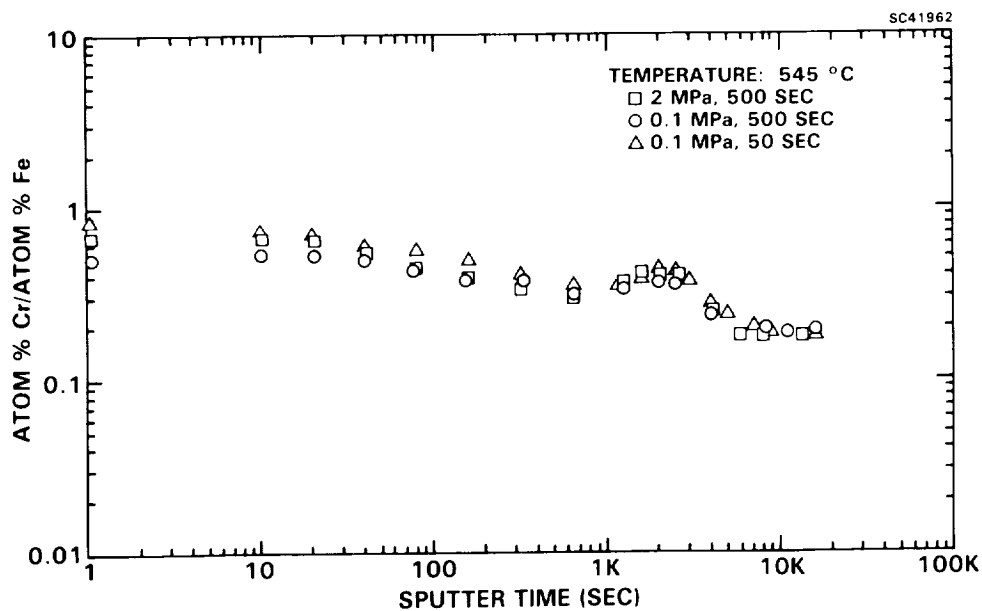


Figure 4 Effect of time and pressure on oxide composition of AISI 440C when oxidized at 545°C.

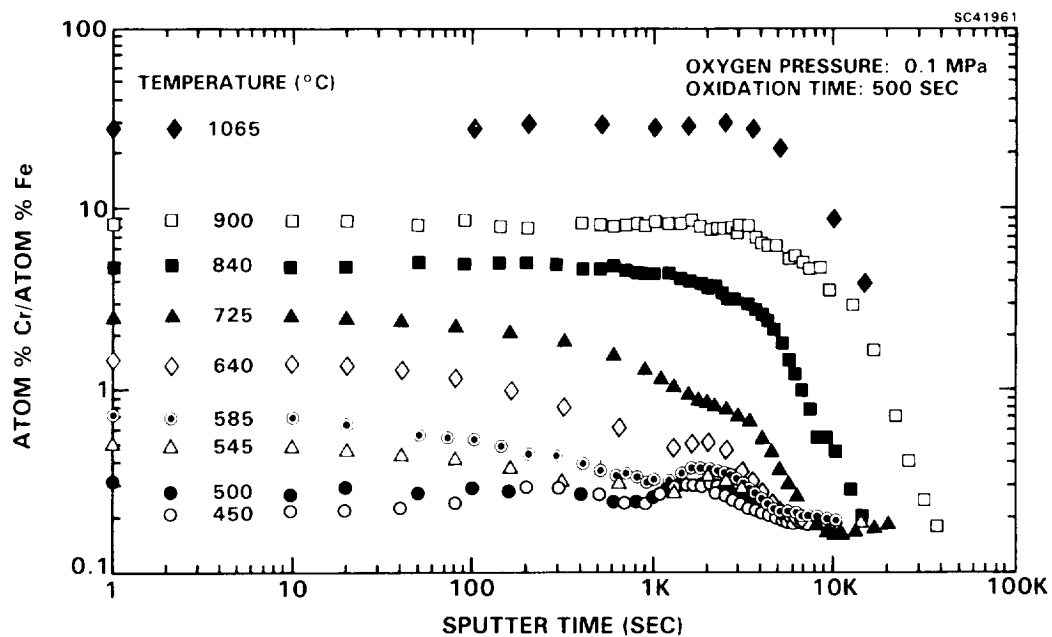


Figure 5 Effect of temperature on oxide composition of AISI 440C when oxidized at 0.1 MPa oxygen for 500 s.

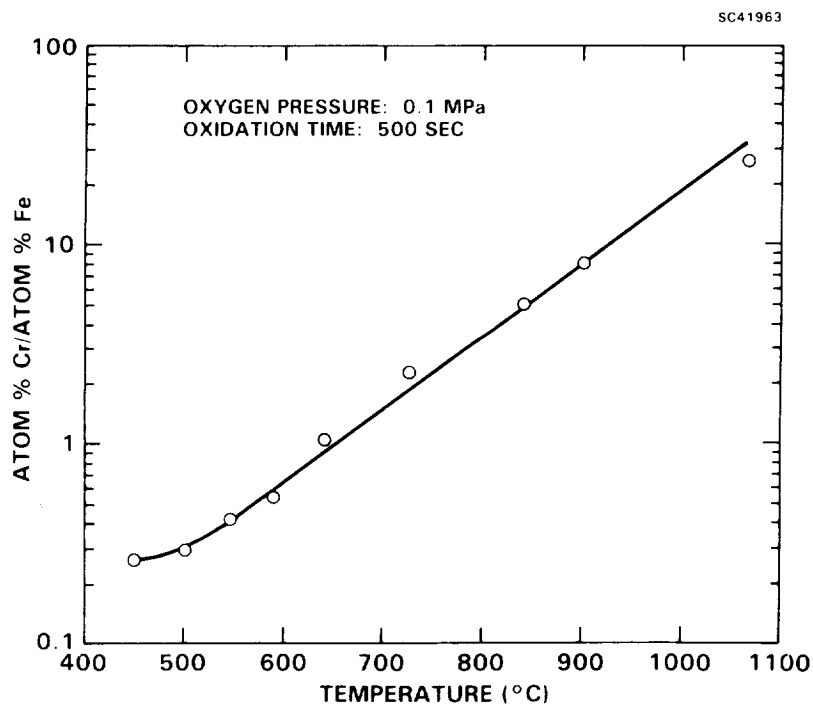


Figure 6 Oxide composition vs temperature calibration curve for AISI 440C when oxidized in 0.1 MPa oxygen for 500 s.

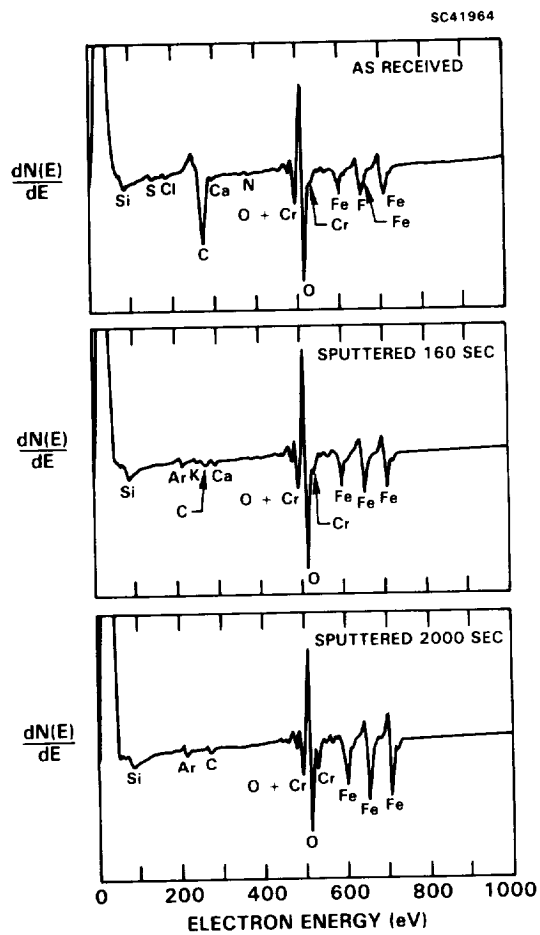


Figure 7 Typical AES spectrum of worn liquid oxygen turbopump bearing at different depths in surface oxide.

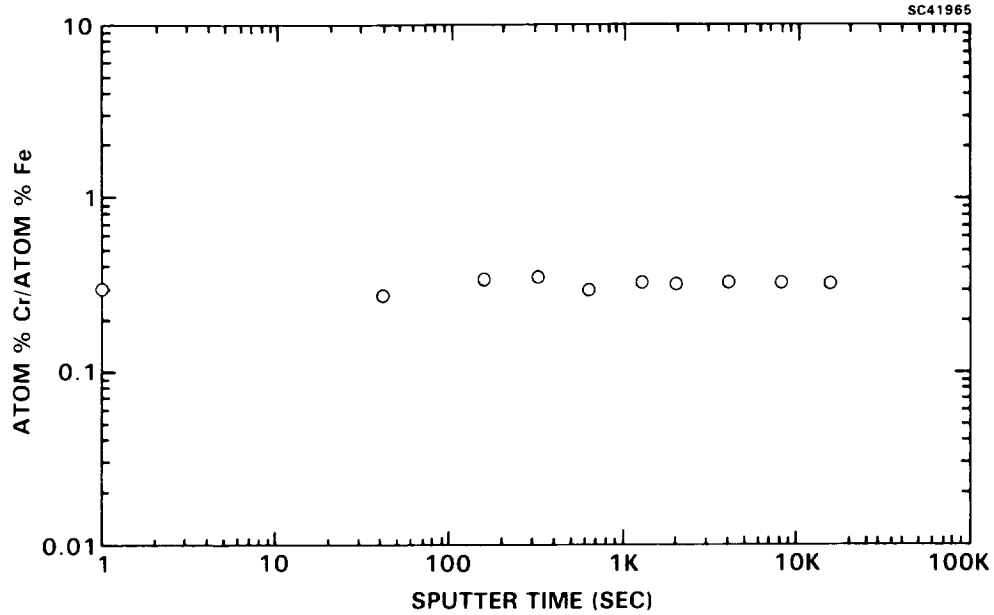


Figure 8 In-depth concentration profile of turbopump bearing in figure 7.

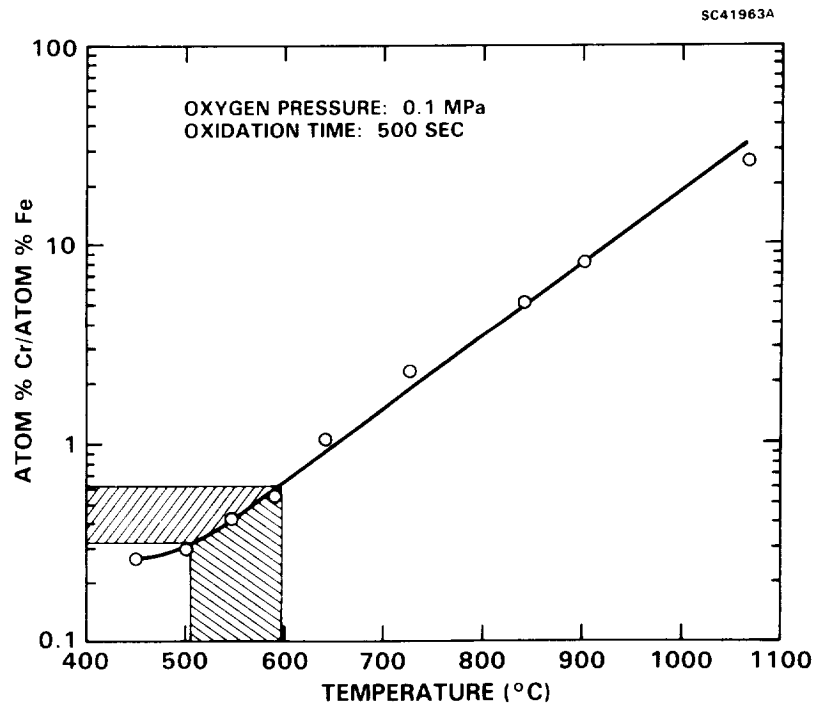


Figure 9 Temperature range for the hot-fired SSME HPOTP bearings.